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ELEMENTARY INTRODUCTION

TO THE SUBJECT OF

VEGETABLE PHYSIOLOGY.

BY

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VEGETABLE PHYSIOLOGY.

PART II.

THE principal object of our former Paper (Journal of the Royal Agricultural Society, vol. xvii., page 62) was to expound, in as simple a manner as possible, the fundamental fact of vegetable organisation, namely, the transformation of fluid substances into solid structures forming parts of a living being, in the development of new cells, the microscopic elements of organic bodies, from formless substances, through the agency of the organising force residing in existing tissues. The general principles there laid down apply to all plants without exception, since the phenomena from which these principles are deduced constitute the first step both in the development of every member of the vegetable kingdom, and in every new part or organ produced by any individual plant. The primary element of vegetable structure, the cell, was described in its most general characteristics—those which are met with in all cells at certain stages of their existence.

In the following pages we propose to furnish such an account as may be intelligible to ordinary readers, of the subsequent history of vegetable cells, and to describe the most important kinds of structure or tissue which enter into the formation of plants. Since, however, the cellular textures constitute only the framework or shell enclosing the matters in which the vitality of plants appears especially to reside, the nature of the fluids and solids contained in the cells and tissues must form a no less essential object of investigation; and indeed, as will be seen from the sequel, the study of the *cell-contents* constitutes, as regards the physiologist, by far the most important branch of the subject. In a practical point of view, above all, such questions as the history of starch and chlorophyll, are of far greater importance than investigations of the forms of cells, the markings of the spiral structures, and the like, interesting as these are in other respects to the philosophic botanist. Admitting, however, the paramount importance of the contents of the cells in reference to the functions of vegetable life, it must not be forgotten that these are limited and defined in their manifestations by the laws which rule over the forms and the arrangement of the tissues, and the organs of which these constitute part. The diversity of character in the life of different plants is principally dependent upon certain fundamental differences in the plan of combination of the elements (the cells). Hence it is necessary at the outset of our inquiry to devote a few paragraphs to the consideration of the general characters of the organization of plants, before entering upon the description of the tissues and cell-contents. This will enable the reader to form juster ideas of the relative importance of the facts which will be afterwards placed before him, by setting the whole upon a more comprehensive basis.

The differences which we perceive in the outward characters of plants are accompanied to a certain extent by differences and gradations of structure in the internal parts, upon which the life of the whole essentially depends. The diversities in the internal anatomy of plants are far less striking than those which exist in the animal kingdom, as may be naturally conceived when we remember how few of the more remarkable vital functions of animals are represented in plants. Moreover, the vast variety existing in the vegetable world is rather dependent upon variations of forms and plans of arrangement (*morphological types*) than upon *physiological* differences. Hence the vegetable physiologist need not concern himself, except as to the great primary groups, with the laws and "patterns" regulating the configuration of the members of the different classes of plants. Leaving these to the botanist *par excellence*, he must especially direct his attention to the modifications of the tissues which are found combined or distributed to a great extent irrelatively, or, at all events, occur in numerous gradations within the limits of the classes whose rank is defined by the plan of arrangement of their larger organs. Let us endeavour to explain this a little more fully. The rank which is given to a plant or animal in classification depends upon the degree to which the principle of specialization, or division of labour, is carried out in it. As the organization becomes more complicated, its parts more mutually dependent, we say it is higher; and while, in regard to physiological functions, the more the different actions are confined to distinct organs, the more exalted becomes the character of the life; so the greater diversity that presents itself in the outward form, and in the modes of combination of the organs, the higher becomes the morphological character. Now the vital functions of plants are so few in kind, and so simple, that their distribution among distinct organs only leads to a comparatively small amount of variation. The chief distinctions between the subordinate classes of plants depend upon differences of form and arrangement of organs which physiologically correspond, and are only unlike in minor particulars, to which it is difficult to assign any physiological value. Then again the structural conditions may vary almost indefinitely in complexity in the same organ within the limits of a single class in both the lower and the higher types. In the Algæ the *thallus*, or vegetative mass, presents gradations from the simple cell, or string of simple membranous cells, to the enormous frond of *Macrocystis* 500 feet in length, where the cells of which different regions of the thallus are composed, exhibit considerable differences both in their forms and functions. Among flowering-plants we find, in the same monocotyledonous class, the palms with their magnificent organization, and the duckweed of our pools, in which the physiological functions are performed by organs constructed on an analogous type, but in the latter case almost rudimentary in their internal organization.

From these considerations it becomes evident that there can be no serial arrangement of vegetable forms in a single graduated scale. We do indeed find a progressive complexity or perfection in the types or plans which characterise the great classes; yet these do not run into one another, but rather stand side by side, exhibiting corresponding gradations, or running out from a common centre into radii of different length.

The vegetable kingdom falls very naturally into two great sub-kingdoms or regions, characterised at once by the outward form (morphologically), by an essential diversity in the internal structure, and by the different degree of specialization of the functions (physiologically). In the lower group we can find no physiological distinctions in the structures devoted to the vegetative life, the general mass of cellular tissue carrying on in common the processes of absorption, digestion, respiration, and development. In the higher group there exists, well-defined in almost every case, a distinction between the absorbing organs (roots), the digestive and respiratory organs (the leaves), and the organ which at once serves to connect these together, and constitutes the focus of development (the stem). This distribution of labour is accompanied, from the lowest forms in which it appears, upwards, by the coincident occurrence of a kind of tissue absent in the lower group; the fibrous and fibro-vascular cords which, connected together and arranged in various ways in the stems, form a bond of union between the organs, and, in the more highly developed plants, constitute a skeleton or framework to support the almost indefinite products of the vital activity of the properly cellular tissues.

The first group are called Thallophytes, from *thallos*, a Greek word signifying a vegetating shoot, and *phyton* a plant. The vegetative structure consists of a homogeneous mass, such as we see in the fronds of Sea-weeds or the scaly patches of the Lichens; and as this vegetative mass or layer is exclusively composed of cells comparatively little changed from their primary conditions, these plants are sometimes distinguished as Cellular plants. The cellular tissue does indeed exhibit very considerable diversities and a considerable range in the degree of alteration from the original form of a membranous sac, as is evident when we compare the simple confervoid filament with the larger Sea-weeds, in which there is a distinction into cortical and medullary tissues, evident both from the form and texture of the cells. But the thallus never presents any trace of those specially metamorphosed and regularly arranged masses of elementary tissue which constitute the fibro-vascular cords of the higher groups.

A most important kind of gradation does, however, present itself within the limits of the Thallophytes, dependent on a matter which we have not yet touched, namely, the specialization of cells in reference to the reproductive functions. In the very lowest forms, as in the fresh-water Algæ, the same cells form in the early part of their existence the organs of vegetation and growth, and at a later period give up these functions and undertake the production of the *spores*, the germs of new individuals for the reproduction of the species. Step by step, in more complex forms of Algæ, the reproductive functions become more localised, at first in certain selected cells of the vegetative mass; afterwards the reproductive cells are found marked for their special function from their very first origin; and in the highest forms, portions of the thallus are developed into peculiar *fruits* or *receptacles*, enclosing and protecting the reproductive cells. These distinctions in the reproductive structures are of great importance in the eyes of the botanist and of the physiologist; but their interest is almost exclusively scientific, and they bear upon practice chiefly through affording instructive illustrations of phenomena of reproduction occurring in an analogous manner in the higher plants, where they are less accessible to direct observation.

The higher of the two groups founded on the characters of the vegetative system comprehends all plants possessing a stem or *axis*, bearing leaves above and roots below, presenting therefore two diametrically opposite directions of growth. The distinctive name of *Cormophytes* has been applied to these, from the Greek word *kormos* a trunk or stem, and *phyton* a plant; the term *Vascular plants*, as contrasted with *Cellular plants*, is likewise applicable to all but the lowest orders. In the simplest members of this sub-kingdom the fibro-vascular structures are present, but represented by elementary organs presenting little variety of conformation; thus in the Mosses they constitute a simple fibrous cord running through the centre of the stem, giving off branches which sometimes run into the blades of the little leaves, but more frequently are confined to the stem, so that the leaves are mere cellular plates like the fronds of the stemless plants. In the Ferns and allied plants there is a great advance, the general characters of the stems and leaves approaching those of the flowering plants; but the inferiority of organization indicated by the absence of flowers, and the intimate connexion of the reproductive structures with vegetative system (evident in the formation of the *spores* on the ordinary leaves of Ferns), correspond to a much slighter diversity and complexity in the conditions and arrangement of the fibro-vascular elementary tissues.

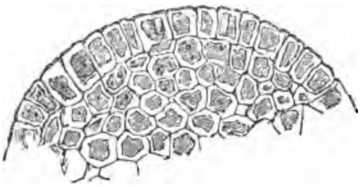
In the Flowering-plants, in the two large classes called the Monocotyledons and Dicotyledons, the different plans of arrangement of the fibro-vascular structures cause a totally different mode of growth of the stems, forming perhaps the most strongly-marked of the characteristics by which these classes are distinguished.

As in the Thallophytes, however, the most important diversities of the sub-kingdom of Cormophytes lie in the mode of development and arrangement of the reproductive organs. In the progressively higher orders these become step by step extricated from their connection with the vegetative system, until in the Flowering-plants we find the organs which produce the reproductive bodies (*seeds*) associated with a complicated collection of specially-metamorphosed organs (sepals, petals, stamens, &c.), while the germs produced are no longer thrown off as simple cellular bodies, but remain dependent upon and nourished by the parent plant until they have acquired their own stem, leaves, and root—that organization, in fact, which distinguishes the vascular stem-forming from the cellular or stemless plants.

The great number of distinct parts, the manifold difference of texture, provision for long duration, &c., involved in the existence of flowers, seeds, and fruits of almost endless variety of character, give occasion, as must be evident, to very great multiformity in the conditions of the fully-developed tissues in the highest class of plants. Among these there are some far more important than others in reference to their connexion with peculiarities in the processes of cell life; and we shall select for consideration here only those principal forms of the fully-developed cell, with which it is indispensable for the vegetable physiologist to be intimately acquainted. We hope hereafter to be enabled to illustrate the general physiological anatomy of the organs of vegetation and reproduction, in a history of the development of the most important agricultural plants.

As the cells of all plants originate in a similar manner, and are essentially alike in their earliest stages of growth, young organs of plants, and their *growing points* or *regions*, are universally composed of a similar tissue, which may be termed *nascent* or *cambial* tissue, constituting as it were the raw material out of which all the special tissues are developed. The cambial tissue, as found in the apex of buds and roots, in the growing regions of stems and other organs, consists of a closely-packed mass of delicate membranous cells gorged with nitrogenous formative matters (fig. 1), and, according to circumstances, with or without starch, chlorophyll, or other assimilated matters and products intermixed with them. Cells in this condition carry on the *development* of the plant by repetitions of the process of *cell-division*, described in our former Paper (Journ. Royal Agric. Soc., vol. xvii. pp. 79, 80). As the cells of the cambium-tissue multiply, the structure increases in size; and in order that a definite form should be given to the product, the cell-development takes place only in certain definite directions. Thus the formative energy is carried onwards with the advancing points of growth, and the tissue which it leaves behind constitutes the substance of the new organs. In the bud of a palm-tree, for example, the summit is occupied by a mass of cambial tissue, in which the cells continually multiply, advancing the growing point, and leaving behind them the cellular substance forming the body of the trunk, together with the lateral masses thrown out from time to time to form the leaves, which run through a peculiar course of development of their own. In our ordinary trees the cambial tissue is not confined to the growing points or buds, but it extends as a layer all over the surface of the stem beneath the bark, forming the seat of the

Fig. 1.



Section of the border of a nascent leaf from the centre of the bud of the cabbage. The cell-walls are scarcely visible until iodine is applied, which coagulates the protoplasmic contents and causes them to contract and leave the walls. Magnified 400 diameters.

annually-repeated development of wood by which the plants of this order acquire their often so enormous dimensions.

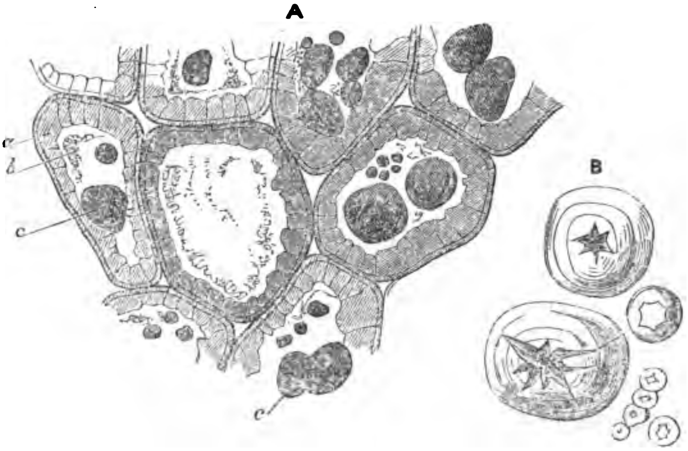
In the cells left behind by the advance of the formative energy in the growing points, or detached from the main body as the foundations of lateral organs (leaves, &c.), it next becomes a question of the first importance, whether they are destined to form the seats of active physiological processes, or are to form parts of the structures by which the physiologically active tissues are protected or supported, or through the medium of which a communication is to be established between the active cells of the different organs and regions. If they are to be devoted to the first office, their physical characters undergo comparatively slight changes: increase of size, and perhaps alteration of form, being the principal affections to which they are subject. They likewise continue to possess the formative and assimilated matters which existed in the young cells; and indeed their life is essentially devoted to the production and conversion of these substances, to supply the waste taking place in the cambium regions, or in the formation of fruits, and to furnish material for the consolidation of the permanent structures of the plant. This *parenchymatous* tissue forms the mass of almost all the structures most important to agriculturists; and in root culture and green crops especially, it is the object of cultivation to increase its quantity relatively to the other tissues. The soft, succulent substance of leaves, of herbaceous stems, and of tuberous roots, of pulpy fruits, &c., is mainly composed of such tissue; and while in a state of active vegetation, its cells are always loaded with the assimilated matters, rendering these productions highly nutritious to animals.

It is important, however, to notice that these cellular or parenchymatous tissues are *transitory* structures. In the natural course of events leaves fall, tuberous roots shrivel up, and succulent fruits fall off and rot. They are developed as temporary nourishing agents, or as reservoirs for accumulated nutritive substance; and nature is too economical to leave the acquired stores in them after the duty is performed. Long before leaves fall off the chief proportion of the assimilated matter is removed from them: the roots of the turnip and beet contain very different qualities of cell-contents in the months before and after their winter rest. And even during the active seasons of growth, if the development, but above all the expansion, of the succulent tissues is stimulated by free supply of heat and moisture, without a proper amount of air and light to insure thorough assimilation, the formative contents of the older cells are carried away to supply material for new growth, or become *diluted* as it were in the unnaturallyexpanded cells, and the result is the production of a weak, watery mass of tissue. The more minute consideration of these points must be reserved until we come to speak of the cell-contents.

We have said that in the succulent tissues the cells become little altered except in form and dimensions; but even in the most delicate of these tissues the membranous 'cell-wall' acquires a certain increase of solidity beyond its original condition. The degree of expansion of each cell of any tissue, being confined within certain limits, the nutrient agency of the formative layer lying upon the internal surface is subsequently directed to the increase of thickness of the membrane, which is effected by the application of new, delicate lamellæ upon the inner surface of the primary membrane, intimately adhering to it. In ordinary cellular tissues these layers of thickening are thin and few in number, and could hardly be detected were it not that they are to a certain extent incomplete, leaving certain spots of various forms of the primary membrane uncovered, which thinner places appear like holes or slits in the cell-wall, although this is not actually perforated. These thinner places occur chiefly on parts of the cell-wall adjacent to other cells, and appear to constitute a means of facilitating the passage of fluids from the cavity of a cell into those of its neighbours. In certain cases the layers of thickening are more numerous, giving a far more solid character to the tissue, which still retains its succulent character; this is especially observed in the cells of fleshy leaves, in the parenchyma of the rind, or of the pith of annual shoots of particular plants, &c.

From cells of this character it is but a step to those which are met with occasionally in organs of transitory duration, which retain the parenchymatous form and active vital functions, while their walls become greatly altered in character. This is the case in certain organs where the cellular tissue is organized as a reservoir of accumulated nutriment, to preserve this during a season of rest, but where this nutriment is laid up, not in the cell-contents, but in great part in structures belonging to the cell-wall. The starch of the wheat-grain, or of the potato tuber, is laid up in delicate membranous sacs, cells which preserve all their original characters as regards the condition of the 'cell-wall.' But the seed-lobes of the bean and pea, the 'endosperm' of the onion seed and of many other plants, are composed of tissue in which the cells have their walls so greatly thickened that their cavities are comparatively small, and the coherent mass of cells acquire a fleshy or horny texture (fig. 2). It may be mentioned in passing that a similar condition exists in the cellular structure of the cartilaginous Sea-weeds; for instance in the caragheen or 'Irish moss, and in Lichens, where the thickening of the walls of the constituent cells converts the whole into a soft horny substance, in which the cavities of the cells occupy comparatively little space. The thickening layers of these tissues are, however, distinguished by their peculiar consistence; they appear to be formed of a modification of cellulose approaching to starch, for not only are they readily softened and dissolved by acids, and sometimes capable even of assuming a blue colour with iodine, like starch, but on the recommencement of vegetation (germination of the seeds) they are, like the starch of wheat or the potato, attacked by the nitrogenous formative layer, which had previously formed them, re-dissolved, and more or less completely removed and conveyed to the developing regions of the young plant.

Fig. 2.

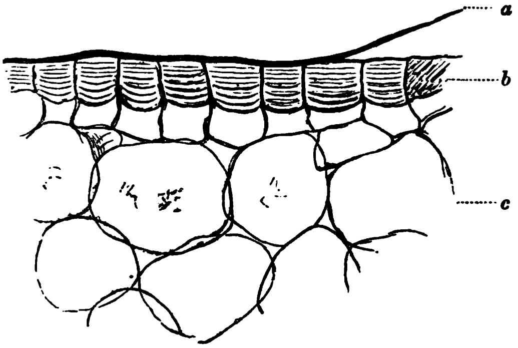


A, Section of the cotyledon of a white haricot bean, showing *a*, the soft thickened cell-walls, which are coloured light-blue by solution of iodine; *b*, the protoplasmic or albuminous substance in the cells, coloured yellow by iodine; and *c*, the starch-granules, coloured deep blue. Magnified 200 diameters.

B, Loose starch-granules, the larger having the striæ, with a central cavity sending out radiating cracks. Magnified 400 diameters.

Structurally related to the foregoing, although very different in their physiological relations, are the cells of the tissue called *epidermis*. So soon as any rudimentary organ of one of the higher plants has attained a distinct form, the layer of cells which form its boundaries, those constituting its entire surface, come into close union at their sides, and, assuming a special mode of increase and expansion, present themselves in the perfect organ as a continuous layer, forming a kind of skin completely investing and perfectly enclosing all the succulent structures, &c. The cells of this layer do not participate in the vital activity of the succulent tissue, and, when complete, are found filled with simple watery fluid, seldom containing starch, colouring matter, or the like, which exist in the subjacent parenchyma. In the great majority of plants that side of the walls of the epidermal cells which is turned towards the external air becomes thicker than the other sides, this being the case to a greater or less extent in different cases, in excessive instances giving the hard horny character to the surface of the leaves observed in many evergreen plants. This thickening results from the deposition of new lamellæ of cellulose on the inside of the exposed wall, which deposition may go on until the cavity is nearly filled up and the cell converted into a solid body (fig. 3). Upon leaves and young stems the thickening layers are generally formed of hard cellulose, obstinately resisting decomposing agents; but the epidermis of many seeds, although of great solidity, has the cells thickened or filled up by lamellæ of a less resisting modification of cellulose, as we see in the horny skin of the seeds of beans, and still more remarkably in the skin of the seed of the quince and linseed (fig. 4), where the cells are thickened by lamellæ of a gummy consistence, which softens and swells up in hot water like the tissue of the seed-lobes of the bean and other leguminous plants. Still further alterations of the epidermal cells, dependent chiefly on chemical operations, as the formation of resinous or

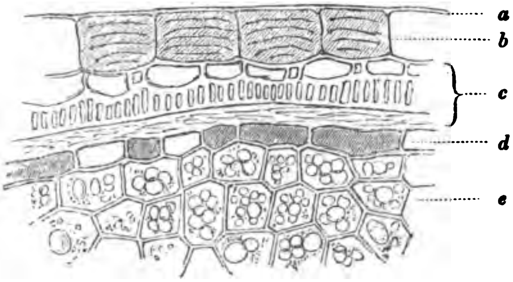
Fig. 3.



Perpendicular section of the epidermis or skin of the leaf of the garden hyacinth, soaked in solution of potash: *a*, the pellicle (never coloured blue by iodine), apparently formed by the chemical alteration of the outer layer of the wall of the cells; *b*, the lamellæ thickening the side of the cell next the surface; the laminated structure is invisible when fresh, and they then are coloured yellow by iodine, but after the action of potash the lamellæ become distinct, and are coloured blue by iodine; *c*, the subjacent cells of the leaf. Magnified 400 diameters.

waxy excretions, and the impregnation of the membrane with silica, will be spoken of more conveniently hereafter.

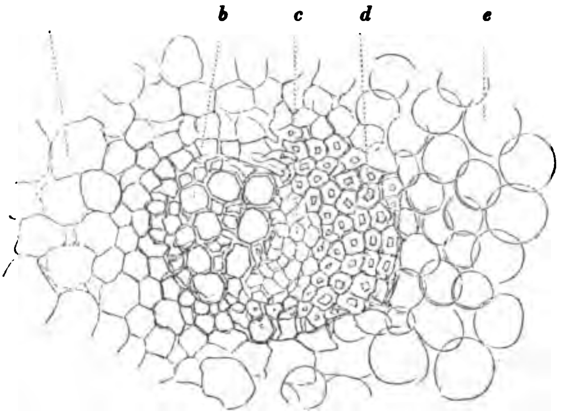
Fig. 4.



Perpendicular section of the outer part of a grain of linseed: *a*, the cuticular pellicle; *b*, the epidermal cells filled up by laminated deposits of the substance which dissolves into a jelly; *c*, subjacent layer of cells of the seed-coat partly obliterated by pressure; *d*, layer of cells containing albuminous substance; *e*, cells of the endosperm, containing drops of oil and granular protoplasm. Magnified 350 diameters.

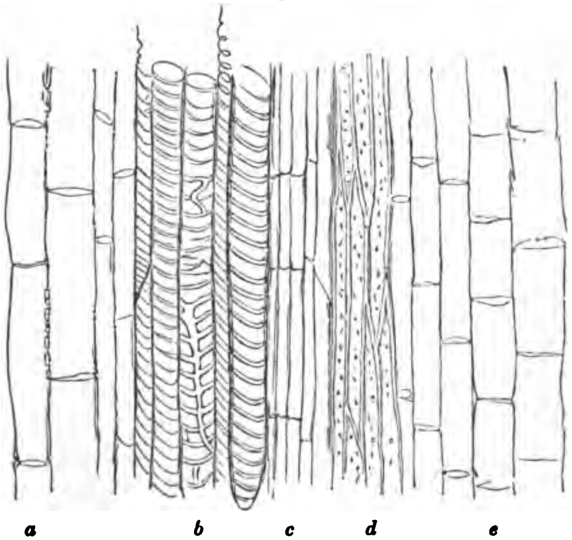
In the lower Cellular plants the fluids conveying nutriment appear to be diffused with great uniformity throughout the whole structure. In plants possessing a stem, and in particular in the Flowering plants, with which we are more especially concerned, the fluids absorbed by the roots flow up in determinate courses through tracts of a tissue which differs in important respects from the parenchyma above described. The cells lying in these tracts exhibit at a very early period a peculiarity of form; they become elongated, and more tubular than sac-like; and if examined in young shoots or stems they will be found to contain colourless matters, while the surrounding parenchyma abounds in chlorophyll, &c. At a very early period of their existence, moreover, the character of a portion of these cells becomes very distinctly marked by the alterations which take place in the cell-wall. Secondary deposits or layers of thickening are formed upon the walls, in lines which have a more or less distinctly spiral course, so that the new substances form spiral bands or ridges upon the inside of the tubular cell, visible externally through the transparent wall; very often this thickening occurs, especially in the larger tubes, in the shape of rings, or of rings or spiral coils connected into a kind of net-work by cross pieces (fig. 5). Cells of this character, more or less elongated, occur in the ends of young shoots of ordinary trees, forming the rudiments of the wood, extending out in bundles into the leaves and other organs as the principal constituent in the ribs and veins, which indeed, in the parts of the flower, are chiefly composed of these 'spiral vessels.' The slender threads traversing the spongy substance of the leaf-stalk

Fig. 5.



A cross section of one of the fibro-vascular bundles of the stem of the white lily: *a*, cellular tissue (next the centre of the stem); *b*, spiral and other vessels and ducts; *c*, cambial or sap cells; *d*, liber cells; *e*, cellular tissue next the rind.

Fig. 6.



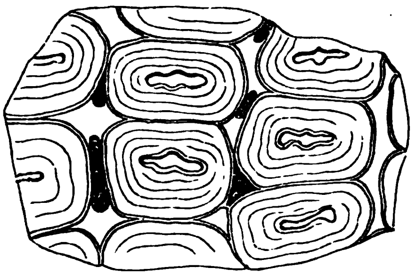
A perpendicular section of the same, giving a side view of the cells and vessels. The letters with the same signification as in the upper figure. Both magnified 100 diameters.

of rhubarb are almost wholly composed of cells containing these spiral and annular layers of thickening, and afford a very convenient opportunity of studying their characters; they may also be seen *in situ* by placing delicate petals, such as those of common chickweed, under the microscope.

It is well ascertained that these tubular cells with spiral or analogous markings lose their fluid contents at an early period; they are always found filled with air or gas when observed in a fresh state, except in the very early stages of development: hence the name of '*vessels*' generally applied to them must not be taken as indicating that they convey fluids like the tubular vessels of animals. They are sometimes called *tracheæ*, as though they represented the respiratory tubes of insects, to which they bear a superficial resemblance. To attribute to them any share in the functions regarded as respiratory in plants would be a great assumption in the present state of our knowledge. Perhaps the most plausible view that can be taken of their use is to regard them as constituting a flexible framework or skeleton, combining strength and lightness, forming a support to the delicate tubular cells with which they are associated, in which the currents of sap appear to flow.

In very delicate organs, such as petals, and in very young stems, &c., the veins, ribs, or 'vascular bundles,' consist of spiral-vessels and allied forms, with the elongated sap-tubes. Such structures form the rudiments of the solid fibres which run out into well-developed leaves, and are combined within the stem into the firm structure constituting the wood. A considerable difference exists in the arrangement and mode of development of these structures in the two principal classes of the Flowering plants—those with a one-seed-lobed embryo, called Monocotyledons (grasses, asparagus, onion, &c.), and those with a two-seed-lobed embryo, called Dicotyledons (bean, turnip, flax, &c.). In the Monocotyledons the vascular bundles remain always isolated, as at first, traversing the stem as separate fibres, as may be seen in cutting across a stem of asparagus, or of the white lily (fig. 5); in the Dicotyledons the bundles, which are developed in a circle, soon come in contact side by side, and form a tube of solid substance separating the pith from the rind or young bark. The causes of these differences cannot be conveniently explained here; and we hope to have a better opportunity hereafter, when we carry on our inquiry into the special examination of the structure of the organs of the more important cultivated plants. The young vascular bundles, as we have said, consist of spiral or similar vessels, with a bundle of tubular cells (sap-cells, figs. 5 and 6, *c*), still in the cambial condition. When fully organized, the greater part of the cambial structure developed in the early stages is converted into wood, or liber-tissue (*d*), which results from the thickening of the walls of those cells by secondary deposits. These layers of thickening are developed in great numbers in many kinds of wood, so that the originally tubular cells become almost solid cylinders, in which state they are sometimes called woody fibres (fig. 7). The liber-cells, forming the woody structures of bark, are much longer in proportion to their diameter than the cells of wood, and from their great solidity when fully developed are often called 'liber-fibres.' The wood-cells, and also the liber-cells to less extent, have their walls marked, by the absence of the thickening layers at certain spots, and a great variety of conditions of these 'pits' or dots occur in the woods of different trees; it is altogether unimportant for our purpose to dwell upon these. It may be mentioned, however, that the wood of most Dicotyledons contains, scattered in the substance of the bundles, large canals formed by perpendicular cells of cylindrical form coalescing at the ends, so as to form a continuous tube. The spiral and annular vessels of fully developed bundles coalesce in a similar way at their ends, and the jointed tubes formed in this way are often called 'ducts.' These 'ducts' are often so large that they constitute tubular channels visible to the naked eye, as may be seen in the wood of oak, mahogany, &c., and likewise in the Monocotyledonous cane, the stem of a kind of palm. The use of these ducts is unknown; in ordinary conditions they contain air, and perhaps they may be regarded as contrivances to lighten the woody structure, and to serve at the same time as 'safety-tubes' into which the fluid contents of adjoining cells may be poured out when the tissue is gorged with sap.

Fig. 7.



Cross section of wood of the Scotch fir, showing the ends of a number of wood-cells. The section having been heated in nitric acid, they are partially separated, and the concentric lamellæ of their walls have become visible. Magnified 400 diameters.

Diverse as we find the forms and the physical conditions of the cell-membranes and their thickening layers in the various tissues of the higher plants, they have a fundamental identity of composition. In all cases they are originally composed of *cellulose*, a substance having a definite chemical constitution, and which is recognizable by certain characters of reaction which can be applied to the tissues under the microscope. The analyses of cellulose show that it is most intimately related to starch, and it is well known that starch acquires a blue colour when it is brought in contact with iodine, a fact which is of great value to the vegetable anatomist in enabling him to detect the existence of starch in the tissues of plants. Cellulose may be recognised by a reaction nearly connected with the above; for when iodine is applied to it either alone or more readily when in conjunction with sulphuric acid, the cell-membrane in certain conditions also assumes a blue colour. The chemical actions which take place here are not yet explained; but the test is an invaluable one, as it is found to have almost universal application throughout the vegetable kingdom. The cell-membranes of some Fungi appear at present as the most important examples of an exception. The connexion of starch and cellulose is indicated both by their elementary chemical analyses and by the above reaction. The reaction with iodine is generally most strikingly displayed in the earlier or little altered conditions of the cell-walls. The excessively delicate membrane of the nascent cells of some Confervæ (*Œdogonium*), and also the very recently-formed layers of thickening in the older cells of these plants, assume a blue colour when treated with iodine alone, much lighter than would be the case with starch, but of the same kind. A similar sensibility to this action of iodine alone exists in the semi-gelatinous layers of thickening in the cotyledons or endosperm of certain seeds (for instance, in certain leguminous plants), where, as was explained above, the thickening matter of the cell-wall is a transitory structure, and is redissolved during germination and appropriated as food, like starch existing in such seeds as cereal grains. But the cell-membranes of parenchymatous tissues generally may be coloured blue by saturating them with strong tincture of iodine, and then wetting them with water. In the same conditions of the cell-wall the application of sulphuric acid, in company with aqueous solution of iodine, brings out the blue colour much more readily. This latter reaction affects almost all membranous cellulose, either of fresh structure or in a dead condition, and may be easily observed under the microscope by wetting a few filaments of cotton wool with somewhat diluted sulphuric acid and adding solution of iodine.

Many old cell-membranes, together with the harder woody tissues in which the cell-wall has received deposits of solid thickening substance, and the thickened cell-membranes of epidermal structures, display a different character when treated with sulphuric acid and iodine. Under these circumstances they assume a deep yellow or brown colour. The observation of their development shows that this character is gradually assumed, and that the same lamellæ, which were capable of taking a blue colour when young, lose this peculiarity as they grow older, and even that in some intermediate stages they may acquire a dirty greenish tint. It becomes a point of importance to ascertain the nature of this change, since it might be attributed to a chemical conversion of the old cell-wall into a substance different from cellulose, or it might be supposed to arise from the cellulose layers becoming infiltrated by substances which disguise its reactions. The latter view is that which is most favoured by the evidence yet obtained. It is found that the structures most obstinately refusing to assume a blue colour with sulphuric acid and iodine, may be brought into a condition, without losing their recognisable anatomical characters, in which they react with tincture of iodine (without sulphuric acid), like young cellulose. A difference presents itself here in the behaviour of two classes of tissues, very differently placed as regards their relation to atmospheric agencies, which may perhaps influence their characters. The structures belonging to the epidermis present a marked difference from those belonging to the internal woody tissues.

In the cells of well-developed epidermis, cork and the cork-like tissues of bark, iodine and sulphuric acid colour the cell-membrane brownish-yellow only. But if sections of these structures are soaked for a long time, or boiled for a short time, in strong solution of potash, and well washed, they are brought into a state (the structure being undestroyed) resembling young cellulose, for if soaked in tincture of iodine, dried, and then wetted with water, they acquire a bright blue colour. Potash will not bring about this change in the cells of wood and fibrous tissues, but nitric acid will; nitric acid on the other hand will not, as a rule, affect the epidermal tissues. Sections of wood, liber, or other structures, where the cells possess firm ligneous walls, assume a yellow or brown colour with sulphuric acid and iodine. When such sections are boiled in nitric acid so long that the yellowish tint, which this acid gives at first, gives place to a bleaching, the tissue is changed, as in the above process with potash. After neutralizing the acid with ammonia and washing away the salt then formed,—saturating the object with tincture of iodine, drying, and then adding water, brings out the characteristic blue colour of cellulose. This possibility of bringing all the solid tissues of plants, in any condition of development, into a state in which they exhibit the reaction of pure cellulose, still retaining their anatomical structure, affords good ground for the assumption that cellulose forms the universal basis of the substance of vegetable tissues, and that the diverse conditions met with in the different parts of plants, and at different ages, depend upon different degrees of consolidation of the substance, admitting a more or less free access to the iodine, and, in the older tissues, to the infiltration of the membranes with foreign substances, which still more strongly oppose the interference of the iodine, and themselves give the yellow colour which iodine and sulphuric acid produce.

It may be worth while to advert briefly here to a certain real metamorphosis of the cellulose membrane. The superficial lamellæ of epidermal-cells, in contact with the atmosphere, appear to be always chemically changed into a substance of resinous or waxy nature, which remains unaffected or is dissolved by the above reagents (fig. 3 *a*). This conversion takes place to a very great extent in some instances, especially in certain fruits, where the transformed lamellæ form a distinct waxy investment, giving the so-called 'bloom' of plums, grapes, &c. The silica which exists in the epidermis of the grasses and other plants, appears to be an impregnation of the outer lamellæ of the cell-wall, hardened in their substance, and not a deposit inside or outside the walls of the cells.

We have now to enter upon the examination of the more important contents of vegetable cells, which, as was shown in our former paper, possess the highest interest for the physiologist, and as they include the principal nutrient substances furnished by plants, must be an especial object of inquiry in reference to agriculture.

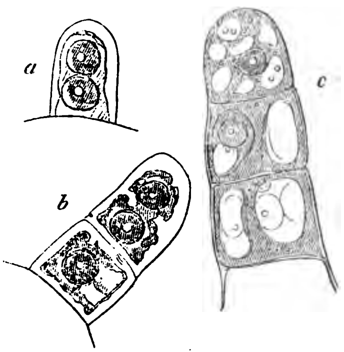
Among the cell-contents we find fluid and solid substances, and some of intermediate consistence. Of these latter, the *protoplasm*, or *formative matter*, is a substance of the first importance. It was shown in our sketch illustrating the ordinary modes of development of cells, that the production of new cells depends upon this substance, and it was at the same time indicated that it takes a principal share in the production of all the other contents of the cells—that, in fact, it is to be regarded as peculiarly the vital part of the structure.

The example selected for illustrating the process of cell-division, the Confervoid filament (Journal, xvii. 79), was chosen on account of the process occurring there in a modification far more accessible than usual to direct observation, both on account of the size and the anatomical condition of the parts. The process takes place in a manner essentially similar in the higher plants, and the young cellular hairs of Flowering plants present a condition very like that of the Confervoids. But in these and still more in the cambial tissues of buds, of nascent leaves (fig. 1), rootlets, and other organs, the cells are excessively small, and so crowded together that the observations are rendered very difficult.

Where the cells are so very small at their birth, and their subdivision is repeated rapidly before they have time to expand, as in the nascent organs just referred to, the protoplasmic matters exist in a state rather different from that in the large tubular Conferva-cell: entirely filling up the cavity of the minute cell, instead of forming a layer lining the cell-wall, so that the constriction here effects simply the parting of one mass of formative substance into two or more, each mass forming its own new cell-membrane (fig. 8, *a*).

It becomes requisite here to direct attention to a body almost invariably existing in young cells in connexion with the protoplasm, and persisting throughout the life of many parenchymatous tissues, namely, the *cell-nucleus*, to which some physiologists attribute the highest importance in the origination of cells, but the real office of which is not yet ascertained. The nucleus (fig. 8) is a body usually of a lenticular form, or the shape of an old-fashioned watch, composed, so far as can be determined by tests applied under the microscope, of the same substance as protoplasm. In full-grown cells where it occurs, it either lies upon the inside of the formative layer (*primordial utricle*), or is connected with this by threads of viscid protoplasm (*c*), holding it suspended in the cavity of the cell. The relative size of the cell-nucleus and the full-grown cell will be best understood from the drawings (fig. 8). It is found that where the cell-nuclei exist in cells in course of multiplication, the first step of the process is the division of the nucleus into two (or, as some affirm, the solution of the nucleus and the formation of two new ones). Such a process even forms the forerunner of the division in *Spirogyra*, described in our former paper, where the drawing (fig. 7, page 79 of Journal, vol. xvii.) shows the two nuclei suspended by protoplasmic threads in the central cavity.

Fig. 8.



Very young hairs from the surface of buds of *Achimenes*: *a*, the hair, a conical cell filled with protoplasm (retracted from the wall through the action of water), containing two nuclei, which nearly fill it; *b*, an older hair, in which the upper part resembles the cell *a*, while the lower is more developed; *c*, a more advanced form, composed of several cells which have expanded considerably, the protoplasm which originally filled the cavity being now "honeycombed" by cavities filled with watery cell-sap; the nuclei adhere to the strings of protoplasm which stretch across the cavity of the cell, and are all connected with a thin layer lining the cellulose wall.

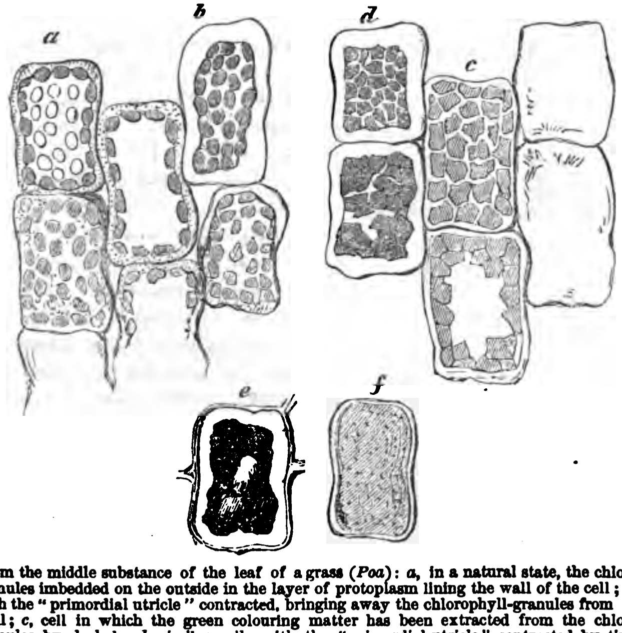
But the relations of the nucleus and its divisions, whatever may be their import, are seen most strikingly in the development of the minute cambial cells of the higher plants. In these the nascent cells are often scarcely larger than the nuclei, which are formed nearly of their full size in the parent-cell before division. This is very well seen in epidermal hairs, where the successive stages of development are presented at one view (fig. 8). In the end cell the nucleus (or a pair of nuclei, if division is about to be repeated) nearly fills the young cell, the formative layer being represented by a thin stratum of viscid protoplasm between the nucleus and the cell-wall. As the cell-wall expands, it departs further and further from the nucleus, which never increases much in size; meanwhile more protoplasm is formed to fill up the intervening space, and this continues up to a certain point. Then a new phenomenon presents itself; in the protoplasm appear lighter spaces, cavities filled with a thinner fluid, which thus look like "bubbles" in the protoplasm; sometimes these increase in number as well as size, and give the protoplasm a frothed appearance; in other cases only one large cavity is formed, which gradually and equably enlarges. When many of the water-spaces exist, as they expand they coalesce more or less; but remnants of the thick protoplasm forming the boundaries of the spaces remain as viscid threads stretching across the central cavity; in this way are formed the threads by which the nuclei are often suspended; in the other cases the nucleus is carried out with the main body of the protoplasm, which by the expansion of the water-space is pushed out, and always adhering to the cell-wall, forms a thicker or thinner layer investing this, presenting the same character as the lining layer of the Confervæ, the central space, occupied by watery-cell sap, forming the great cavity of the cell. The protoplasm is, however, much increased in quantity during the expansion of the cells of succulent parenchymatous tissues destined to form the seat of nutrition, especially in leaves and other green parts, also in cells which are destined to produce starch. In leaves we find a rather thick layer applied against the cell-wall (fig. 9), in which it is not easy to ascertain whether a distinct (formative) layer lies immediately upon the cell-wall; the protoplasm is of denser consistence near the cell-wall, and when contracted by re-agents presents a smooth, even surface where it was in contact with the membrane. In some of the Cellular plants the character of the protoplasmic layer is more distinctly seen, and it there presents an appearance of distinct layers, of different consistence, the densest next the cell-wall. The layer immediately applied to the wall seems to be efficient in cell-formation, while the inner thicker layer is more devoted to the nutrition, judging from the chlorophyll-granules which lie imbedded in it. In the *Chara* the circulating substance is a third stratum, lying inside that layer in which the chlorophyll-granules are imbedded. In the cells of the leaves of Vallisneria, the chlorophyll-granules are imbedded in a rather thin layer of transparent protoplasm, which extends as a sheet over the inside of the cell-wall, and "circulation" observed in the cells consists in the travelling round of the entire stratum of protoplasm, carrying along the chlorophyll-granules and the nucleus with it; by which indeed the motion is rendered visible.

The circulating movement of the protoplasm in the interior of cells is observed in many young cells, and may perhaps be universal in early stages of growth; but in most nascent tissues it is difficult to get an observation without injuring the structures so much as to disturb the internal economy of the cell, through endosmotic or exosmotic actions. It may be seen very well, however, in young hairs of Flowering plants, which, projecting from the epidermis of organs, may be examined without the necessity of dissection. In these the movement is seen in the protoplasm lining the walls, and in addition, the viscid threads which run across the cavity and connect the nucleus with the primordial utricle move about, change their form, and carry along the nucleus with them. The protoplasm is usually almost colourless in these cases, and the motion is only rendered visible by the presence of minute granular matter which always exists in the protoplasm. These movements cease very early in plants growing in air, but they persist in the cells of many water-plants, where the movement may be seen not only in the transparent young organs, but in sections of the full-grown leaves, &c., where the presence of chlorophyll-granules above referred to renders the movement very evident.

It has already been shown how important the protoplasmic cell-contents are in reference to the formation of cells (Journal, xvii. 78 *et seq.*), and we shall have presently to direct attention to the evidence of their agency in producing the various other substances which are met with in living cells. But protoplasmic substances are not only accumulated in the cells for the purposes of reproduction or nutrition of the individual cell in which they occur; we find tissues in what we may term the "resting" structures of plants, wherein the cells are loaded with a store of protoplasmic matter to serve as material for future wants. This is especially the case in seeds, buds, bulbs, tubers, and the like. The outer layers of the cells of the endosperm of the corn grains, beneath the hard skin, and the cells in the vicinity of the embryo, contain no starch, but are filled with protoplasmic nitrogenous matters in the form of globules or granules of semifluid consistence (fig. 11). A small quantity of this same substance exists with the starch in the inner cells. A portion of the cells of the embryo of beans (fig. 2) and pease exhibits a similar character, and this accumulation of assimilated nitrogenous matter is a constant phenomenon in seeds. As will be shown hereafter, this matter is removed from the cells and consumed by the young plant during germination.

None of the substances met with in the contents of cells have greater claim to the attention of the physiologist than *chlorophyll*, or "leaf-green," as it is sometimes termed. It is well known that the characteristic green colour of vegetation depends upon the presence of this substance; further, that its production is entirely dependent upon the action of sun-light on the contents of cells, and that its formation under this influence is directly connected with the evolution of free oxygen, the result of a decomposition of the very highest importance in the nutrition of plants. Although, however, it has been experimentally ascertained that the formation of the green colouring matter takes place in consequence of an action of the sun's light, and that the quantity in a given plant is as a rule proportionate to the amount of this action, great obscurity prevails when we attempt to go below the surface of these general statements. Moreover, although we see every day that the formation of the solid structure of plants, and of the more highly elaborated products rich in carbon, bears a relation to the activity of the chlorophyll-forming process, it is at present quite unsettled what that decomposition is which gives rise to the formation of the green colouring matter. Added

Fig. 9.

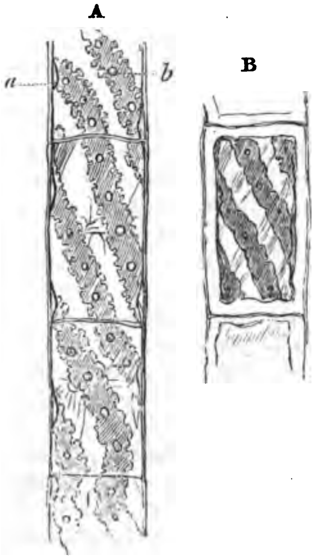


Cells from the middle substance of the leaf of a grass (*Poa*): *a*, in a natural state, the chlorophyll-granules imbedded on the outside in the layer of protoplasm lining the wall of the cell; *b*, a cell with the "primordial utricle" contracted, bringing away the chlorophyll-granules from the cell-wall; *c*, cell in which the green colouring matter has been extracted from the chlorophyll-granules by alcohol; *d*, similar cells with the "primordial utricle" contracted by tincture of iodine; *e*, cell treated with a solution of potash, converting the whole contents into a green granular viscid mass contracted from the cell-wall, but hollow internally; *f*, a cell treated with acetic acid, the contents entirely converted into an olive-coloured fluid containing minute point-like granules. Magnified 400 diameters.

to this, very superficial and incorrect notions prevail widely as to the physical and chemical qualities of chlorophyll, and its developmental relations to the other substances occurring in cells.

Chlorophyll is ordinarily found in the form of rounded granules, flattened in one direction, lying imbedded in the layer of colourless protoplasm lining the cell-wall. In this condition it may be readily observed in the internal cells of the leaves of the grasses (fig. 9, *a*), and even more clearly in the cells of the leaves of the water-plant Vallisneria. The depth of the colour and the number of granules vary according to circumstances, both being increased by active solar influence. When the granules are so numerous that they are crowded together, they often assume a hexagonal form, so as to fit closer together, but even when thus crowded, they are not immediately in contact, a thin layer of the colourless protoplasm being always interposed between them.

Fig. 10.



A. Portion of a filament of *Spirogyra*, with the green colouring matter in the form of broad bands (*a*), spirally arranged; in the bands lie groups of minute starch-granules (*b*), which appear as bright points, but are coloured blue by iodine.
B. A cell laid in syrup, in which exosmotic action has caused the colourless primordial utricle to contract, carrying the green bands with it, leaving the cell-walls free. Magnified 200 diameters.

When fully developed, chlorophyll is ordinarily granular, and situated as described upon the wall of the cell, but there are exceptions to this rule, especially among the flowerless plants, where the chlorophyll sometimes occupies the centre of the cell, surrounding the nucleus, and sending out radiating processes (*Anthoceros*), while in other cases it presents itself in the form of bands and streaks running over the cell-wall, quite distinct from the layer of protoplasm immediately applied to this (*Spirogyra*, fig. 10). In many cases also, where the chlorophyll is ultimately found in the form of distinct large granules, it appears at first like a mass of soft granular protoplasm, of a light green tint, from which the granular bodies are gradually formed. Thus in the cells just beneath the corky skin of potatoes (containing little or no starch), which have become green by exposure to light, the green colour is found first in the threads of viscid protoplasm which stretch out from the nucleus across the cell. In young cells of the leaf of a moss (*Hypnum*) the chlorophyll appears at first as a green irregular mass, which is subsequently organized into distinct granules.

It is very common to find chlorophyll granules described as consisting of a waxy or fatty substance, and chemists have generally very readily accepted this account, from the circumstance that the green colouring matter of leaves, &c., may be extracted by alcohol, and the substance thus obtained is of the nature just described. But this alcoholic extract yields a substance which is itself a compound, since a colourless waxy substance may be obtained from it, separately from the true colouring matter, which exists in very minute quantity. Not only is this green waxy matter a compound substance, but, what is of still more importance, it constitutes but a part of the constituents of the chlorophyll granules. When the green colour is extracted from chlorophyll, *in situ*, by the action of alcohol, under the microscope we find the granules left behind in their original position, only colourless (fig. 9, *c*). The green colouring matter may be observed at the same time upon the slider, at the evaporating edges of the alcohol, deposited in fat-like globules of very irregular size, some large from confluence while in solution.

A deeper investigation into the behaviour of the chlorophyll granules leads to a still more decisive refutation of the assumption that the chlorophyll granules are masses of coloured wax. When we open the cavities of cells so as to allow the escape of chlorophyll granules into the water, under the microscope, we find them swell by absorption of water, and a kind of endosmotic action is set up, bubble-like spaces often becoming hollowed in the interior (fig. 17, *b*), into which the water penetrates and "blows out" the granules. The edges of these swollen granules are found to be finely granular or minutely ragged. The bubble-formation through absorption of water is seen still more clearly in the green bands of *Spirogyra* above referred to, where it also reveals that the green colour resides only in the outer part of a colourless band of viscid substance, which is coagulated and contracted by the application of alcohol or most acids (fig. 10, B). When alcohol is applied to cells containing chlorophyll granules, for instance those of the grasses, the granules when decolorized mostly swell up at first, and subsequently become solidified, seemingly by coagulation. Tincture of iodine applied to the decolorized granules colours them deep brownish-yellow, the same colour which it imparts to the primordial utricle, the nucleus, and protoplasmic matters generally (fig. 9, *d*).

When the chlorophyll-bearing cells (for instance of a barley-leaf) filled with granules are digested in solution of caustic potash, the granules are at first swollen, then they gradually coalesce into one mass, which contracts (apparently with the primordial utricle separated from the cell-wall closely investing it) and forms a finely-granular heap in the middle of the cell (fig. 9, *e*); this mass commonly exhibits a rather large central cavity filled with colourless liquid. The granular mass retains its bright green colour for several days; its granular appearance is chiefly dependent on exceedingly fine green points, probably minute globules of the green fatty colouring matter. The granular substance, with the green colour equably diffused, greatly resembles the green cell-contents of some microscopic Algæ, such as *Protococcus*.

When the cells are soaked in strong acetic acid, the form of the chlorophyll-granules is quickly lost, and they, together with all the rest of the cell-contents, coalesce into an olive-coloured liquid (?) substance, filling the entire cavity of the cell. In many cases this liquid exhibits numerous blackish molecules, probably separated globules of fatty substance (fig. 9, *f*).

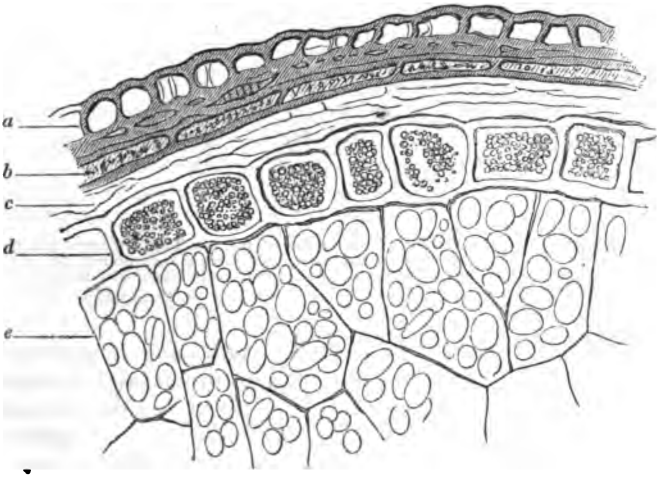
The anatomical conditions, together with the reactions just detailed, which on the whole are the same as those exhibited by the colourless protoplasmic cell-contents of other cells,—making exclusion of the green substance soluble in alcohol,—lead to the conclusion that what is commonly described as chlorophyll is a somewhat complex and, to a certain extent, variable matter. It appears legitimate to assert that the basis of chlorophyll-granules, bands, &c., is formed by protoplasmic (albuminous) substances organized into definite forms, and in such a state of chemical composition that the action of light causes the formation, within their mass, but from without inwards, of a fatty matter associated with a green colouring principle. The fatty matter must exist in an intimately divided condition, and its presence in a kind of suspension probably causes the greater resistance of the outer than the inner part of the granules to the action of water, causing their expansion, vacuolation, and even bursting by endosmose of water. In a few cases the green-coloured fatty substance is developed at once in the ordinary protoplasm of the cell, in masses and streaks, or diffused uniformly throughout a granular mass filling the cells.

The green colouring principle may be separated from the fatty substance; it is present only in extremely small quantity, and its analysis shows that it contains nitrogen, which is absent from the fatty basis. Its origin and characters are still involved in great obscurity. This green matter of chlorophyll is closely connected with the colouring matters of autumn leaves, red cabbage, beet, &c., but this subject will be best dealt with separately hereafter.

The above-described conditions of chlorophyll present features of still greater interest when we consider them in connexion with *starch*, since these two substances are very commonly present together, and several hypotheses referring to the evolution of oxygen by green organs have been based upon suppositions of convertibility of these substances one into the other. It will be most convenient to postpone the consideration of these questions until we have examined the characters and the developmental history of the starch-granules themselves.

Starch is at once one of the most important and most widely diffused of all the substances produced in the interior of vegetable cells. It is met with in all classes of plants except the Fungi, at some period of their growth, and in almost all tissues while in a young condition. It occurs, however, in greatest abundance in certain special tissues or organs, which on this account become of high value in an economical point of view. It is almost superfluous to say that we refer here to seeds, such as the cereal grains, &c. (fig. 11), tubers, like the potato and the analogous root-like subterraneous stems of the arrowroot plants. In the sago-plants it is accumulated in the parenchyma of the trunk, and even in ordinary trees it is found in considerable quantity in the winter season in the inner parts of the bark, the outer part of the wood, and in the pith in the neighbourhood of the winter-buds.

Fig. 11.

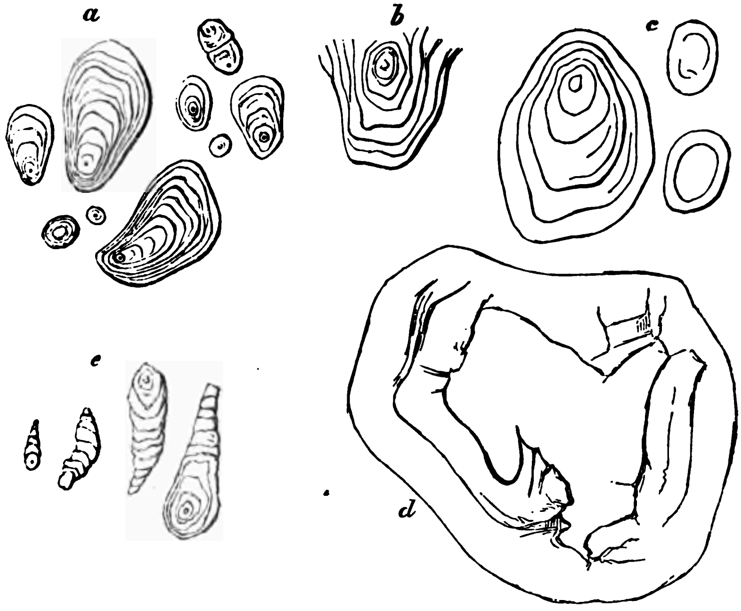


Section of the outermost part of the wheat-grain: *a*, the epidermis with a subjacent layer of cells almost obliterated by pressure; *b*, cells with thick and punctated walls; *a* and *b* are more or less coloured, *b* giving the brown colour of bran; *c*, a layer of clear colourless substance formed by the obliteration of several layers of cells through pressure; *d*, large thick wall-cells filled with finely granular protoplasm, without starch-granules; *e*, cells, with delicate membranous walls, filled with starch granules, forming the mass of the grain.

It is when thus collected in quantity that starch is of most consequence in the eyes of the agriculturist, but the physiologist is no less interested in its presence in smaller quantities in the cells of actively vegetating tissues, since it here evidently plays an important part in the general history of the nutrition of plants.

The characters of starch are best examined in some of those structures just referred to as containing it stored up in large quantities in their cells. If we place beneath the microscope thin sections of a potato-tuber, we perceive that its bulk is composed of membranous sacs or cells, containing a quantity of *granules* of very varied sizes, but of a form tolerably definite in all the larger examples. (See fig. 4, Journal, xvii. 75.) The smallest of these *starch-granules* are globular, the largest are more or less regularly egg-shaped, and intermediate forms are found in the intervening sizes (fig. 12*a*). In all but the smallest, concentric streaks may be observed, indicating a lamellated structure, the lamellæ being proportionately more numerous as the granules are larger (and older); this structure may be roughly

Fig. 12.



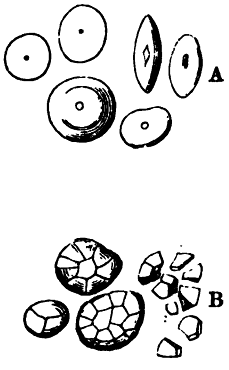
Starch granules of the potato: *a*, various forms in the natural condition, the larger ones characteristic; *b*, a granule heated so as to cause a peeling-off of some of the concentric coats; *c*, granules swollen by heating in water; *d*, granules softened and "blown-out" by more violent action of hot water; *e*, granules in course of solution, from a growing tuber. Magnified 400 diameters.

compared with the formation of the bulb of the hyacinth or onion, of coats successively enclosing the whole; the granule being transparent, the boundary lines of the successive layers or "shells" are seen through the whole thickness. The lamellæ are of very unequal thickness, and in the granules of the potato they are thickest at one side, or rather end, concentrically surrounding a minute point visible near the smaller end, which in the fresh granules is seen to be a minute cavity filled with liquid, and in dried starch appears to contain only air. Here and there in potato-starch are granules of medium or small size, and different form, with two or more of these central points or *foci*, each with a certain number of concentric layers, and then the outer layers running uninterruptedly round the whole as single coats, enclosing double or triple granules; this condition is far more common in some other plants.

The lamellæ are not only different in thickness from each other and in their own different parts, but the outer layers are of denser consistence than the inner; this may be shown by their action upon polarized light, but it is very evident also in their behaviour when solvent reagents are applied to the granules; another indication of it is afforded by the fact that in thoroughly dried starch the inner layers shrink, and radiating cracks are perceived in the interior, running out from the point-like cavity.

The starch occurring in the cells of the mealy structure of the corn-grains is essentially similar to that of the potato, but there are great differences of form of the granules, both from potato-starch and among different kinds of grain. The starch-cells of wheat are delicate membranous chambers (fig. 11, *e*), with closely adjoining flattened walls, and they contain numerous granules, of very unequal sizes, the larger of which exhibit the characteristic form for this plant, that of a flat doubly-convex lens; the point or cavity is central, varying in size, and concentric striæ are less easily distinguishable than in potato-starch (fig. 13, A). The starch of barley is in grains somewhat similar, but larger, the outline of the form being often rather squarish, and the sides more flattened, while the edges are thicker. The starch grains of rye are much like the foregoing. The larger of the starch grains of oats appear at first sight like irregular, rounded, more or less globular bodies, in which may be perceived interconnected streaks

Fig. 13.



A. Starch-granules of wheat.
B. Compound starch-granules of oats; the right-hand figures crushed down. Magnified 400 diameters.

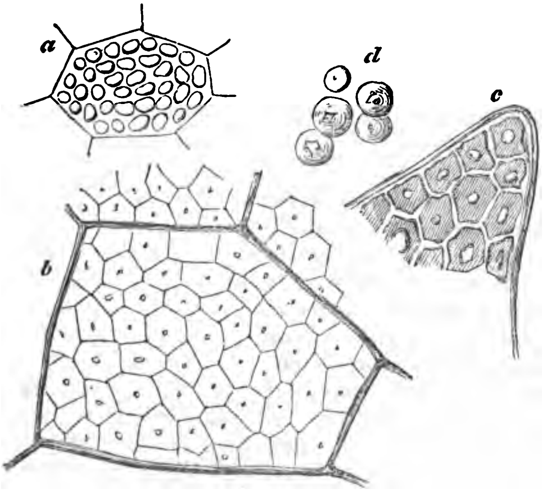
(fig. 13, B); when the granules are crushed down, it is recognised that these streaks are the lines of union of a number of irregular granules, each with its own "point" connected firmly together into a *compound granule.*

Starch is found in the seeds of beans and peas, in the form of roundish granules (fig. 2), with indistinct striation, and having the internal substance very soft, so that when they are dried the central cavity becomes comparatively very large, running out into wide cracks.

The starch of the rootstocks of the plants of the arrow-root and ginger families, yielding the various pure starches known by the names of "arrow-root" and "*tous-les-mois,*" furnishes a number of round and highly-developed forms of the starch-granule. In *tous-les-mois* the granules are somewhat like those of a potato, but much larger and with more regular and delicate concentric streaks. The starch sold as arrow-root is derived from various plants, but the grains of genuine kinds are mostly recognizable, being very unlike those of potato, *tous-les-mois*, or the cereals.

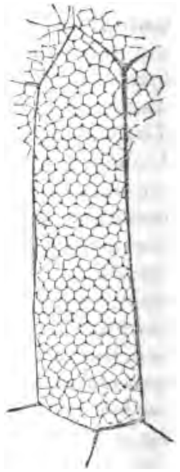
The starch of maize, at least in part, and that of rice, present peculiar conditions. In maize (fig. 14) the granules found loose in the inner cells of the seed are small and more or less rounded, but

Fig. 14.



Starch of maize: *a*, young cell with the nascent starch-granules imbedded in the formative protoplasm; *b*, full-grown cell with the perfect starch-granules densely packed; *c*, fragment of a similar cell treated with solution of iodine, which colours the starch-granules blue, and the intervening protoplasm brownish yellow; *d*, free starch-granules, from a cell where they are not compressed through crowding. All magnified 400 diameters.

Fig. 15.



Cell of rice-grain, showing the very numerous small starch-granules so densely packed that they form a solid horny mass. Magnified 400 diameters.

the outer cells of the seed are filled with starch-granules so densely packed that they are flattened against one another (*b*), and present angular forms, fitted together like stones in a wall; they all present rather a large central cavity. In rice (fig. 15), where the granules are exceedingly small, they are packed in the same way, but even more densely, whence arise the horny character of this seed, and the granular nature of its flour, in which the starch-granules are but imperfectly separated from each other.

The starch occurring more sparingly in the cells of vegetative tissues appears both in the *simple* and the *compound* form, the granules being usually far smaller than in the above-described examples—often so small that their nature can only be determined after causing them to swell up by applying certain reagents. The microscopist's universal test for starch, where the size or appearance of granules leaves their nature in doubt, is iodine, which colours the starch-granules a more or less deep violet or blue, according to the strength of the solution. Alcoholic tincture of iodine is often used; but this is apt to deposit crystals of iodine in the water in which the object lies, so that a solution of iodine in an aqueous solution of iodide of potassium is more convenient. When starch-granules have been previously treated with dilute sulphuric acid (which is done to swell them when very minute), the blue colour inclines to purple, more or less reddish, according to the amount of action of the acid. The nature of the combination of iodine and starch is yet unexplained by chemists, but the fact of the colouring produced is of the highest interest, not only on the ground of its value as a test, but from the relations indicated to the softer forms of cellulose above described. Starch-granules extracted from the potato, for instance, and viewed free in water, appear as solid bodies insoluble in cold water. They are found to contain a variable proportion of water in their substance according to the extent to which they are dried. The statement that they are not altered by cold water is only absolutely true of the external denser lamellæ, since we have found that, by crushing freshly-extracted granules, and allowing water to have direct access to the inner lamellæ, these occasionally swell out to some extent by absorption of water, and deform the grain, the outer lamellæ resisting the action. When the water is heated (and applying diluted sulphuric acid or solution of potash has the same effect), the granules swell, the streaks disappear, the internal substance softens into a jelly, and the whole swells up into a large gelatinous mass, having, however, still a definite outline. The phenomena here exhibited vary a little. Sometimes the softening and swelling are uniform; the whole granule is then as it were blown out into a gelatinous bubble, probably from endosmose of water, and the granule is thus converted into a thin jelly-like sac, still insoluble in water. Very often the power of resistance is unequal at different parts of the structure, and the granule is first of all "blown out" out into one or more partial sacs or bulgings, which ultimately coalesce when the whole expands. This appearance may be produced by allowing sulphuric acid to run in upon the granules from one side of the slider. Still more frequently the granule bursts while swelling up into a sac (fig. 12, *d*), and then we not unfrequently find some of the internal substance extravasated in cloudy patches, which are rendered visible by applying iodine to the object.

When the starch granules of the potato (or *tous-les-mois*) are carefully heated on a dry slider of glass, and placed beneath the microscope, they present one of two appearances, the difference depending seemingly on their degree of dryness. They either split up, or rather *exfoliate*, the concentric coats cracking and peeling off one after another (fig. 12, *b*), or they become softened, lose the streaks, turn brownish, and swell into globules presenting a large central cavity formed by the expansion of the air contained in the original small point-like cavity (fig. 12, *c*). In both cases the starch has undergone decomposition as well as change of form; it has now become soluble in water, having been converted, in fact, into the gum-like substance called *dextrine*. The continued action of sulphuric acid, of boiling water, of substances producing fermentation, &c., likewise converts starch-granules into dextrine or sugar; and doubtless this conversion leads to the solution of the starch of seeds, &c., during germination. But in the processes of germination the solution of the granules takes place without a previous swelling up into starch-jelly, and the appearances vary in different plants.

When the starch of a well-sprouted seed-potato is examined, the large granules are found in various stages of diminution of size by superficial solution, by no means coincident with the concentric coats: the end containing the cavity persists longest (fig. 12, *e*). The compound granules of oats fall apart in germination, and are then dissolved from without inward. The grains of barley (as observed in malt) exhibit a different mode of solution; holes are formed in the outer coat, and the solution gradually eats out the contents, leaving a shell; singularly enough the same appearance occurs also in potato-starch when acted upon by fermenting yeast.

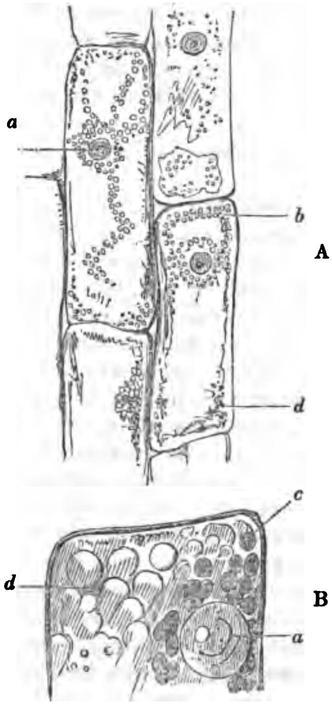
The mode of origin or development of the starch-granule has formed a subject of considerable debate among vegetable physiologists, but the principal facts may now be considered as ascertained. From the laminated character of large grains of starch, several observers were led to compare the starch-granule with a cell having its wall coated with layers of thickening, and they explained the development as follows: the granules originated as vesicles, which by nutrition expanded and simultaneously formed a second coat *inside* the first, and so on, all the older expanding at each addition in the interior. This notion was supposed to be borne out by the fact of the inner lamellæ being softer and less resisting than the outer; but this circumstance admits of satisfactory explanation in another way.

Starch-granules occurring in leaves and other actively-vegetating organs are almost always small, and scattered through the cell-contents. When the cells of such structures are carefully observed at the periods when the starch is in course of formation, the starch-granules will always be found in connexion with the protoplasmic or albuminous matters, sometimes in the nucleus, very often in the viscid strings of protoplasm running out from this, or imbedded in the layer lining the wall of the cell (fig. 16 B). Still more frequently, in green organs, are the starch-granules found in the *interior of chlorophyll granules:* to this point we shall return presently.

Observations made upon seeds, tubers, &c., in which the large, often highly laminated, granules occur, throw a greater light upon the subject: we there see that the connexion with the albuminous matters is a necessary one—that, in fact, the starch granules are formed through the agency of the protoplasm. It is found that the granules originate, in their earliest form of small round granules, in minute cavities which are produced in the substance of the protoplasm. Step by step in the larger forms the protoplasm deposits the layers which constitute the concentric coats, until the full size is attained. The excentric position of the minute cavity or point in potato-starch, *tous-les-mois*, &c., seems to arise from that end of the granule at which it lies being pushed out, as it were, from the general surface of the layer of protoplasm, thus hanging into the cavity of the cell, invested by a thin coat of protoplasm, by which it is less freely nourished than the other end. The compound granules, like those of oats, &c., are formed by a number of granules originating near together in the same mass of protoplasm, and, coming into contact, they become fitted together, and at last the intervening substance vanishes, so that they become firmly coherent. The double and triple granules sometimes found in the potato have the outer coats completely enclosing the whole, the external mass of protoplasm having deposited this after they had come completely into contact.

The formation of starch from the protoplasm is well seen in the grain of maize (fig. 14). At an early stage the starch cells are densely filled with protoplasm or albuminous matter. The granules first appear in this as small globules, separate, and uniformly diffused through the protoplasm; solution of iodine colours them blue, while the matrix of nitrogenous matter turns yellow. By degrees, in the outer parts of the grain, the grains enlarge, until they come nearly into contact, and, to adjust them closely together, their original rounded form changes to polygonal, in which shape they appear densely packed in the ripe seed. On applying iodine to sections of the ripe seed, however, a thin stratum of yellow protoplasm is seen interposed between the adjacent grains.

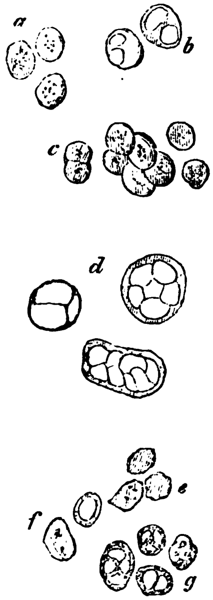
Fig. 16.



A. Cells from the stem of the white lily, containing nuclei (*a*) adherent to the protoplasm (*d*) lining the cell-wall, and, more or less connected with these, tracts of protoplasm, in which are forming chlorophyll and starch granules (*b*). Magnified 200 diameters.

B. Fragment of another cell magnified 800 diameters, after treatment with iodine: *a*, nucleus; *c*, starch granules imbedded in protoplasm (*d*), which in other parts exhibits "vacuoles," or water-bubbles.

Fig. 17.



Chlorophyll-granules, producing starch; *a*, young chlorophyll-granules; *b*, similar granules, with water-bubbles caused by endosmose; *c*, round chlorophyll-granules coherent in groups; *d*, the same in a more advanced stage, containing starch-granules, the chlorophyll forming a mere film over the surface (all the above from the young fruit of *Sphærocarpus terrestris*); *e*, *f*, *g*, chlorophyll granules from the prothallium of a Fern; *f* and *g*, older ones, in which starch-granules are forming. All magnified 1000 diameters.

The presence of this formative protoplasm is evident in the starch-cells of the potato after they have been boiled. If a portion of the "floury" substance is placed under the microscope, it will be seen that the cells have become separated from each other, and that they are also swollen from the softening and expansion of the starch-granules. On the membranous walls of the cells will further be perceived reticulated lines, which are the coagulated remains of the protoplasm which intervened between the granules. With iodine these assume a yellow colour.

The connexion existing between the starch-granules and chlorophyll has already been noticed. Some of the more important features of their relations will now have become evident from what has been stated above respecting, on the one hand, the true nature of the chlorophyll, the fact especially of its having a basis of protoplasm or albuminous matter,—and, on the other, of the origin of starch-granules from a matrix of the same or similar material.

Chlorophyll-granules are found in all the vegetating organs of green plants, at some period of growth, having one or more small starch-granules in their interior. The size of the starch-granules, in comparison with that of the chlorophyll-granule containing them, varies extremely; sometimes the starch appears as one or more bright points in the substance (coloured blue when treated with iodine), sometimes the single starch-granule, or a confluent group of granules, appears surrounded by a mere film of chlorophyll (fig. 17). These differences of size are shown, by comparative observations on the same plant, to depend upon the age, that is, the degree of development, of the starch-granules; they grow up from an almost invisible point in the interior of the substance of the chlorophyll, just as free starch-granules do in the colourless protoplasm of seeds, tubers, &c. Chlorophyll-granules containing starch-granules are very well seen in many of the lower plants, as in the leaves of Mosses and Liverworts, especially in spring (fig. 17). Largish granules also occur imbedded in the bands of *Spirogyra* (fig. 10, A, *b*), and they occur abundantly during active vegetation in the green protoplasmic contents of the Confervoid Algæ generally. The closely-packed layer of chlorophyll in *Chara* has the granules sometimes so loaded with starch, that they form a dirty-blue layer when iodine is applied. In the higher plants the chlorophyll-granules of the deeper-seated tissues of green organs, as the middle substance of leaves, and the cells of the rind nearest the wood, present starch-granules more frequently than those in cells lying immediately beneath the epidermis.

It is observed that, generally speaking, the substance of chlorophyll-granules which contain starch is of denser consistence; it does not absorb water so readily, and exhibit the "water-bubbles" above described. The application of water to chlorophyll-granules set free, only causes the line bounding the contained starch granule or granules to become better defined. The chlorophyll-granules containing starch usually acquire larger size than those in which it is not formed.

The starch-granules found in chlorophyll are by no means permanent deposits; they occur during very active vegetation, and vanish again (by solution?) in subsequent stages of development. They disappear in this way from the chlorophyll of leaves in autumn; but the phenomenon is especially well seen in the Confervoid Algæ, where the starch regularly disappears preparatory to the cell-division or the conversion of the green cell-contents into spores or reproductive cells.

The character of these corpuscles of chlorophyll containing starch-granules, has been interpreted in a different way; they have been regarded as starch-granules which have become encrusted by chlorophyll, the order of development having been assumed to run in the reverse direction from that just described. This has formed the basis for a chemical hypothesis of the origin of chlorophyll, which however fails not only on this ground, but also on its chemical basis, since it assumes at the same time that chlorophyll consists simply of the green-coloured fatty matter, leaving out of view the albuminous basis demonstrated by the experiments related in a preceding page. Mulder considered that fatty matter of chlorophyll was formed out of starch by a decomposition in which a quantity of oxygen was liberated. The process of conversion was supposed to extend inward from the surface to the interior of the pre-existing starch-granules. The origin of the green colouring substance (existing in very minute quantity), admitted to contain nitrogen, was not satisfactorily explained.

This hypothesis is in contradiction—first, to the essential nature of the solid basis of the chlorophyll-granules, a mass of protoplasmic or albuminous substance; secondly, to the observed history of development of the chlorophyll-granules which contain starch-granules; and, thirdly, to the fact, confirmatory of the evidence on the second ground, that chlorophyll-granules originate in cells of young organs wherein no trace of starch can be detected until afterwards. Still more striking are the cases of the green bands of *Spirogyra* and other Confervoid Algæ, which are never preceded by a starchy deposit of the same form.

Cases do indeed occur where chlorophyll-granules containing starch-granules increase in size, the starch-granules forming a "nucleus" for the chlorophyll; but that the starch affords the material for the production of the chlorophyll is in opposition to the fact that most frequently the starch-granule does not contemporaneously diminish in size, but in fact often grows larger. Even in such peculiar cases as that of the potato-tuber "greened" by exposure to light, the circumstance that the chlorophyll of the outer layers of cells, which contain little or no starch, is formed in the protoplasmic substance, warrants the supposition that in the more deeply-seated starch-cells those starch-granules which become coated with a layer of chlorophyll received this as a deposit from the protoplasmic substance which we know to exist diffused through the cell, and that the starch-granules are probably dissolved and diffused in the cell-sap before being utilised for new developments.

The evidence, then, furnished by the history of development of chlorophyll- and starch- granules, leads us to conclude that the relation of starch to chlorophyll is chiefly, if not entirely, dependent on the fundamental identity of the albuminous substance, forming the material basis of the chlorophyll-granules, with the protoplasm or nitrogenous formative matter of the cell.

The matters belonging to the cell-contents, which have up to this point been examined, are at once substances very generally when not universally diffused in the vegetable kingdom (the Fungi affording the exception as regards chlorophyll and starch), and at the same time accessible to microscopic investigation. Various other products remain to be enumerated, to which those characteristics only apply partially, or are even inapplicable.

Fatty matters or fixed oils may be regarded as very generally present in plants, and they occur for the most part in conditions analogous to those in which starch is found; indeed, fixed oil is not unfrequently found replacing previously existing starch-granules in the very same cells, possibly through a transformation. Oils are often to be detected, by the microscope, by their standing suspended in drops of variable size in the cell-sap. If abundant, the drops are often large, and their nature may be determined not merely by their optical characters, but by their confluence under pressure and their solubility in ether (fig. 4, *e*). In living cells they are never in immediate contact with the cell-membrane, but lie inside the albuminous lining of the cell, and adherent to the masses of protoplasm. In many cases where the oil is in small quantity it is so intimately combined with albuminous substance that it cannot be detected by simple inspection under the microscope; but heating the cells, so as to solidify the albuminous matters, often causes the separation of the oil in drops. Drying up oil-bearing cells will likewise cause confluence of the drops, and, when the albuminous lining of the cell is destroyed or injured, the oil readily soaks out through the cell-membrane, as is observed in old seeds which have become "greasy."

Examples of cells containing fixed oils are afforded by many well-known seeds, such as linseed (fig. 4), seeds of poppies, cotton, castor-oil, many palms, &c., in the "endosperm" or substance formed to nourish the embryo; and in rape, nuts, almonds, &c., in the cotyledons of the embryo itself. It is a point deserving especial remark, that starch occurs in these same structures before they are completely developed, and vanishes subsequently. We observe in the lower Algæ, again, that the starch of the vegetative cells is replaced by drops of oil in what are called the "resting-spores,"—the reproductive cells capable of bearing drought or winter-cold without losing their vitality, which in these plants represent the seeds of the Flowering plants.

Comparatively little is known at present regarding the production of these fatty matters; undoubtedly they are nearly related in their origin to starch, from which they differ in composition chiefly in the diminution of the proportion of oxygen. A certain proportion of oily matter occurs very generally in structures abounding in starch, such as potatoes, or with starch and "soft" cellulose, as in beans and pease, where it is apparently suspended in the albuminous protoplasm. Possibly a portion of the fat given in analyses of the green parts of plants, as of grass (and dried as hay), may be derived from the chlorophyll.

Dextrine and *sugar* are substances of universal occurrence in plants, but, being excessively soluble, they are generally found only as constituents of the watery cell-sap, invisible to the microscopist, and only to be discovered by ordinary chemical examination of the juices; yet they are really among the most important of the products of the cell; and their formation and their transformations, in company with starch, cellulose, and the other substances devoid of nitrogen, constitute some of the principal operations of healthy vegetation.

We have seen above that starch-granules are converted into dextrine by heat, sulphuric acid, and other agents. This conversion occurs in the cells of starchy seeds in germination, as is seen in malted barley. Since, therefore, we find dextrine in the expressed juices of the organs of plants which are in a state of active vegetation or development, while it is replaced in a great measure by starch, cellulose, or fixed oils in resting organs, we cannot avoid the conclusion that dextrine constitutes one of the transitory, soluble forms of the neutral ternary series of compounds (cellulose, starch, &c.) holding the assimilated food in a condition in which it is directly applicable for organisation through the medium of the albuminous formative matter.

The various sugars—grape-sugar, cane-sugar, &c.—stand in much the same position as dextrine in reference to development; they occur in similar situations dissolved in the watery cell-sap, abounding often in young shoots, succulent stems, &c., especially at the epoch just previous to flowering. Sugar is formed in company with or probably from dextrine, out of the starch of germinating tubers and seeds; so that it is not merely a product of simple assimilation, but, like dextrine, also a soluble material capable of being derived from decomposition of more highly elaborated matter (starch and cellulose) where this is required for new development.

We have spoken of dextrine and sugar as dissolved constituents of the watery cell-sap, and this is their general condition. When sugar is very abundantly formed, it is sometimes deposited in crystals, forming a kind of excretion, as is observed in parts (nectaries) of various flowers. This phenomenon, however, is of minor importance physiologically speaking, and is of far less interest than the occurrence of solid gummy matters, approaching very closely in character to dextrine, and at the same time distinctly related to cellulose. Gum arabic, the gum of plum and cherry trees, are exudations from the stems of trees, ordinarily regarded as excretions resulting mostly from disease. They are supposed to be derived from the watery cell-sap; but this is very doubtful, for it has been shown that gum tragacanth, which exudes from various species of *Astragalus*, is essentially analogous in its nature to those semi-gelatinous thickening layers of the cells of seeds described in an earlier page, only that the approach is here to dextrine and not to starch. In the tragacanth-plants the parenchymatous cells of the pith and the medullary rays have their walls greatly thickened as they grow old with the "soft" cellulose compound, which in time loses to a great extent its laminated character, and, undergoing a chemical modification, becomes almost homogeneous, acquiring at the same time the property of swelling up strongly when placed in water; so that the access of wet to the stems causes these cells to swell up, burst, and exude in a gummy mass upon the surface of the bark. The gummy matter obtained from quince-seeds and linseed consists in like manner of the soft thickening layers of cells, that is of cellulose approaching in physical condition to dextrine, retaining its structure (fig. 4) until a late stage of its existence, but passing chemically into a condition in which sulphuric acid and iodine do not readily produce a blue colour. In tragacanth gum treated with those reagents, fragments of cell-structure are revealed in the gelatinized mass; the mucilage layers of quince seeds turn blue with a more active iodized preparation (iodide of zinc). The slimy substance of the Confervoid Algæ, and the gelatinous tissue of the larger sea-weeds, appear to consist of a similar substance, *i. e.* cellulose metamorphosed structurally and chemically into a homogeneous substance intermediate between cellulose and dextrine, insoluble in water, but naturally containing a great quantity, and passing into a horny condition if dried.

Inulin and *pectin* are products which have been described and studied by chemists, and their relations with starch and the soluble ternary compounds seem very close. The microscope is, however, of little avail in the investigation of these substances, since they present no definite structure as they exist in nature. Inulin is extracted from the tubers and tuberous roots of various plants of the botanical order Compositæ, such as that of the Jerusalem artichoke (*Helianthus tuberosus*), the root of elecampane, the dahlia, &c. It is obtained separate by extraction with boiling water, which in cooling deposits a structureless granular substance, which is not coloured blue by iodine. Its composition is the same as that of cellulose, and it is very readily converted into sugar; hence it would appear to be a substitute for starch and dextrine peculiar to certain plants.

Pectin is obtained as a gelatinous matter from various fruits, such as apples, pears, &c., and from roots, such as the turnip and carrot, by boiling, and its occurrence in large quantities in the economical plants imparts to it a high claim to the attention of physiologists. Unfortunately the chemical part of its history still presents a somewhat complicated and uncertain collection of results, which are incapable of being brought into relation with the other facts of the nutrition of plants. The analysis of pectin shows that it differs from the starch and cellulose series in not containing oxygen and hydrogen in the proportions of water. It is found in ripe fruits, with sugar, where vegetable acids have been previously abundant, and it is said to be produced from unripe fruits by boiling with sulphuric or malic or tartaric acids. Now as the cell-walls of the succulent tissues of fruit are somewhat hard and resisting before ripening, and afterwards become very delicately membranous, the substance (outer lamellæ of the cell-wall ?) originally cementing them together dissolving away, pectin would appear to be derived from the action of acids upon cellulose; hence it approaches in its mode of origin to dextrine, but the chemical composition opposes an obstacle to any further comparison between them. The investigation of the subject of pectin, especially in connexion with the growth of turnips and mangel wurzel, is one of the pressing desiderata of agricultural science.

The further constituents of the watery cell-sap are to be regarded as rather special than general, for such of them as occur indiscriminately in all parts of plants are rather unassimilated products carried forward in the diffusion of the sap than proper cell-contents. Among these are the dissolved gases, carbonic acid, oxygen, &c., mineral salts, salts of ammonia, &c. The compounds of mineral bases with organic acids form a special class of products, some of them occurring probably in most of the higher plants in particular stages of growth. Their presence has been chiefly noticed, and their relations to vegetative life examined, in the cases where they exist in especial abundance, in soluble (malates, nitrates, oxalates, &c.) or insoluble (oxalate of lime) conditions. The oxalate of lime occurs in great quantity in a crystalline form in certain plants. The study of these compounds in reference to vegetable life lies at present wholly in the province of the chemist.

The colouring matters of plants (exclusive of chlorophyll) are at present very imperfectly known as regards their chemical relations to each other and to the other substances met with in cells. Their mode of origin is, anatomically, similar to that of the watery cell-sap in colourless cells, as described in a former page (20), with the difference, that in the excavations or "vacuoles" formed in the viscid protoplasm is produced a coloured watery fluid, usually clear and transparent. As the young colour-cell expands, the separate accumulations coalesce in the central cavity of the cell; but the entire collection is enclosed by the albuminous layer lining the cellulose wall, through which it never passes, although a watery juice, during the life of the cell. We may very often observe two adjacent cells with watery fluids of different colours, which, in the natural state, do not intermix, although separated but by the delicate cell-walls. When such cells are placed in a solution contracting the primordial utricle, the latter shrinks up a little, and then mostly bursts and emits the coloured watery fluid which exudes through the cellulose membrane. Not unfrequently granular bodies occur in the watery fluids of colour-cells; these have not been properly examined.

The colour-cells of petals and other organs of flowers lie in one or more layers immediately subjacent to the epidermal layer of cells. The peculiar colours of the leaves of certain plants—as of red-cabbage, beet, &c.—arise from the sub-epidermal layer of cells being filled with a colouring fluid, like that of petals, instead of containing chlorophyll as usual. The chlorophyll of these plants lies in the deep middle region of the leaves, and is screened by the interposed red cells, to which it imparts a bluish or greenish tint. In the red cabbage the ribs and veins of the leaves have brighter red tints because there is no subjacent chlorophyll in those parts, which are white in the green cabbage. The red and the distinct yellow and orange hues which many green leaves assume in autumn, owe their tints, in the first instance, to the formation of a coloured watery liquid in the same sub-epidermal cells which contain the colour of red-cabbage leaves; but very often, as in the Virginia-creeper, the alteration gradually affects the cells all through the leaf. The tinted liquid appears to be formed at the expense of the remains of the chlorophyll-granules, since these are found in small number in cells in process of change, gradually losing their colour, and then vanishing, until the cell is filled with a coloured fluid, which may be extracted either by water or alcohol, but most readily by the latter. So far as we could ascertain the point, the albuminous lining of cell ultimately disappears here, leaving the coloured liquid in direct contact with the cellulose membrane. The brown colour which the fallen leaves subsequently assume, and which many leaves acquire in the first instance, without displaying red or yellow tints, arises from the transformation of the cell-membranes into humus, the first step of their decay into vegetable mould.

The leaves of other trees turn almost white when they are about to fall. This depends upon their cells assuming a condition similar to that which is constant in the white patches of "variegated" leaves. The chlorophyll and other contents vanish, leaving scarcely anything but the empty cell-membrane behind. The white patches and spots of variegated leaves are well known to depend on the absence of chlorophyll in the subjacent parenchyma, and they therefore constitute a disease. The common *Aucuba*, or "spotted-laurel" of our shrubberies, is a diseased plant of this kind, having perfectly green leaves in Japan. The disease is hereditary here because it is always grown from layers, and not by seed.

The colouring-matters of fruits are similar to those of autumn leaves in regard to their replacing chlorophyll previously existing in the same cells; but we observe here greater variety of colouring, resembling what occurs in the coloured organs of flowers.

The subject of the colouring matters producible from vegetable structures, such as indigo, madder, &c., is beyond the scope of the present paper, but, when further investigated, will probably throw much light upon the chemistry of vegetation.

The aromatic or essential oils which are found more or less abundantly in a great variety of plants are mostly formed in special cells, occurring singly or grouped into the so-called "glands," in connexion with the epidermal structures. The cells containing these oils are, when fully developed, filled with the secretion, which is separated from the cellulose wall by a thin layer of protoplasm (primordial utricle). When observed in younger stages it is perceived that the oil-cells are originally filled with the protoplasm or albuminous substance, and that the oil is excreted in drops into hollows formed in this. As the oil-drops increase, and the protoplasm is absorbed or consumed, the drops coalesce, until at length they displace all the protoplasm except the layer lining the wall of the cell. The conditions are analogous to those above described of the cells containing watery fluid colouring matters; and it is through the agency of the thin layer of albuminous matter that the oil is prevented from exuding through the cell-wall in the living cell. When this pellicle is disorganised the oil soaks readily through the cellulose-membrane. Most of these aromatic oils consist of a mixture of an oil liquid at common temperatures with a substance analogous to camphor or stearoptene, solid at common temperatures when separate. Stearoptenes are found alone, generally in a crystalline form, in the wood of various aromatic trees; but their developmental history, as well as that of the various resins, is still involved in obscurity.

The so-called "milky juices," such as abound in the roots of lettuces, dandelions, the stem and foliage of poppies, spurges, &c., exist in special tubular reservoirs, which appear to be intercellular passages into which the secretion has exuded; some authors, however, believe these canals to be formed by the confluence of rows of cells. The juices are not "milky" until exposed to the air; they consist of clear fluid containing dissolved albuminous matters, with globules of resin and sometimes starch-granules in suspension; the milkiness disappears again when they dry up, and there remains a resinous substance, varying in consistence and composition in different plants—often, as in the case of the opium-poppy, the lettuce, &c., containing the active principles to which the plants owe their economic or medicinal value.

Nothing general can be stated at present regarding the production of these juices, which, however, deserve careful investigation, since they exist in small quantities in a great variety of plants, and give the special value to a number of species or genera useful to man. These juices are interesting to the physiologist, moreover, like the volatile oils, on account of their important connexion with those chemical processes in which oxygen is liberated, since they are either hydro-carbons or poor in oxygen, and their abundance in a given plant stands in relation to the amount of exposure to solar influence. This relation is not confined to the oily or resinous matters, but holds good of the active principles (alkaloids, &c.) mixed with them. The class of Conifers (pines, firs, &c.) appears to form an exception to this relation of resinous secretions to the sun's action, since they belong especially to high latitudes and mountains; possibly their persistent evergreen foliage may have some influence in producing the abundance of highly-carbonised secretion.

It is now time to look back over the particulars which have been expounded in the foregoing pages, in order to see how far we are enabled to draw from them any general physiological conclusions. One thing strikes us at first sight—the absolute necessity of entering upon the examination of the phenomena in their microscopic detail,—since we have found that even the simply chemical, like the vital, processes take place in what we have termed the organic or physiological "atoms," the cells. Each of these is a little apparatus in itself, executing its special duties in more or less close association with its fellows, and the physiological functions of the plant represent the sum of the diverse actions of a multitude of these, which we have seen to be more and more limited to special or individual operations in proportion to the variety existing in their organisation and arrangement. For this reason it is requisite to devote the greatest attention to these *minutiæ* of the appearances and changes in the contents of cells, which have been described at some length in the present paper. Only through an intimate knowledge of the phenomena presented in the actively vegetating cells, can we hope to arrive at a clear comprehension of the essential facts, and the general laws of the nutrition of plants.

The accounts of the mode of development of cells given in our former paper (Journal, xvii. 62), and of the formation of the various products of the cell described in the preceding pages, demonstrate the extreme importance to vegetable life of those principles commonly called "albuminous," characterized by a definite composition into which nitrogen enters. These, which the chemist distinguishes into albumen, fibrine, legumine, &c., the microscopist recognises, under the name of *protoplasm*, as the seat of the vital activity of the plant, whether evinced in growth or in the assimilation of nutrient substances. On a former occasion we found them reproducing the cells themselves; in the present paper it has been shown that not only is the cell-membrane produced by their agency, but that they form the basis of the chlorophyll-granules, produce starch, oils, colouring matters, and apparently also the soluble matters of the watery cell-sap. And not only do they produce all these things, but they have the power of decomposing and reconstructing almost all of them, as may be required by the local or temporary exigencies of the plant, so that they form a sort of centre or medium with which all the processes of vegetation are more or less directly connected.

We may venture to suppose, therefore, that the ternary substances, the cellulose and starch, &c., series, are produced through the agency of the nitrogenous principles; that the latter consequently are the primary substances in vegetable assimilation. The question then arises, How and where are these nitrogenous principles produced? From the presence of the protoplasmic matter abundantly in rootlets, from its existence in quantity in Fungi and in other plants grown without access of light, we are led to think favourably of Mulder's opinion that these matters may be formed directly in the roots of plants; the recent experiments of Boussingault, of growing plants in sand, with only mineral substances, where the use of nitrate of soda caused a production of nitrogenous principles equal to what would have been obtained in a fertile soil, seem to show that as a rule the nitrogenous substances are taken up by the roots, and the *protoplasm* may be produced there from nitrates or ammoniacal compounds.

The further question then presents itself, How do the ternary compounds originate? Judging from anatomical investigation, we may answer, from the albuminous substances, but in what manner, and where, we are not prepared to say. The hesitation with regard to these points arises from the changeable and ubiquitous characters of these ternary principles. Yet we have some data. There is certainly strong negative evidence afforded in the inability of Fungi, colourless parasites, and etiolated plants, to produce any considerable development of cellulose in their texture, or, as regards the Fungi, of starch-granules in their cells. Nitrogenous substance is found abundantly in these cases, but the cellulose products are weak and perishable. If the protoplasm had the power of assimilating carbonic acid and water without the peculiar solar action which causes the green colour of chlorophyll, we do not see why there should not be abundance of cellulose, &c., in those cases where nitrogenous matter abounds. There is reason to think that organic compounds are taken up in these instances to afford material for the production of the cellulose; and this seems to be borne out by the influence of humous substances in the manure applied to turnips. But ordinary plants do not form their due quantity of cellulose, starch, &c., unless they receive the influence of light, causing a green coloration of their foliage.

Our attention is thus directed to the chorophyll granules, as the agents of assimilation of the ternary substances; those granules formed of "protoplasm," which, under the influence of light, become impregnated with a waxy matter containing a green colouring principle. We know that this matter is produced in proportion to the amount of solar action, *provided a sufficient supply of nitrogenous matter is afforded to the roots;* further, that the quantities of ligneous cellulose, starch, oil, and the more highly carbonized essences, resins, &c., are all similarly proportionate to the formation of chlorophyll. But we are arrested here. A multitude of questions at once crowd upon us, to which we cannot give any answer. Does the assimilation take place in the formation of the waxy matter? What is the import of the green colouring principle? Is all the assimilated matter first combined in the chlorophyll-granules, and then decomposed in the dark into dextrine, &c.? Or do the granules work by "contact-action," whatever that may really signify? Further, does the soluble assimilated matter, which may exist as dextrine and sugar, when formed by direct assimilation, or by decomposition from starch, fixed oils, or soluble cellulose (amyloid), merely mix with, or enter into combination with the albuminous substances, which use it for reconstruction in other situations? That it enters into mixture at least is evident by the way in which cellulose, starch, &c., are formed upon its free surfaces by a kind of excretion; there is no contact-action upon a surrounding medium when starch-granules are formed in cavities of the substance of the albuminous matters, any more than when watery-cell-sap, containing dextrine or sugar, is exuded into newly formed vacuoles: still less when a cellulose membrane appears suddenly upon the surface of the free mass of protoplasm, lying in water, as in the germination of the zoospores of the lower Algæ. Through what means and with what changes of their own constitution the nitrogenous matters are enabled to take up and lay down, as we may express it, the so-varied secondary products of assimilation, are questions of extreme complexity, altogether obscure at present; and they present remarkable difficulties in the way of investigation. So much knowledge, however, has been attained in recent times in the domain of organic chemistry, that every encouragement is offered to the prosecution of these inquiries. In the mean time there is abundant work for the microscope in investigating the special cases of cultivated plants in their varied conditions and stages of growth. This alone can furnish a key for the explanation of the different composition of structures in different stages, revealed by chemical analyses, since it is evident that the diversity depends upon the operations which have their seat at a given epoch in the cells of a given tissue, not in accidental differences of a general "sap" passing through the organs.

Through the joint efforts of the chemist and the anatomist, with a more extended use of the experimental method, we may hope to arrive in time at the true theory of vegetable nutrition, and to solve also the problem of the "circulation" or "diffusion" of sap in plants.

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